AD-A037 955 WELLESLEY INSTRUMENTS CORP WALTHAM MASS F/G 20/5
A DUAL ELECTRO-OPTICAL LIGHT IMAGE RECEIVER AND RECORDER.(U)
JAN 77 E P MORSE F19628-76-C-0206
UNCLASSIFIED AFGL-TR-76-0002 NL

| OF |

AD
A037955

END
DATE
FILMED
5-77

AFGL-TR-77-0002

A DUAL ELECTRO-OPTICAL LIGHT IMAGE RECEIVER AND RECORDER

By

Edward P. Morse

WELLESLEY INSTRUMENTS CORPORATION
225 Crescent Street
Waltham, Massachusetts 02154

January 1977

Final Report for Period 1 May 1976 to 31 January 1977

Approved for public release; distribution unlimited

Prepared For
AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) (19) AFGL-TR-76-0002	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) A DUAL ELECTRO-OPTICAL LIGHT IMAGE RECEIVER AND RECORDER,		5. TYPE OF REPORT & PERIOD COVERED Final Report. May 1976 - 31 Jan 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Edward P. Morse		8. CONTRACT OR GRANT NUMBER(s) (15) F19628-76-C-0206 NEW
9. PERFORMING ORGANIZATION NAME AND ADDRESS WELLESLEY INSTRUMENTS CORPORATION 225 Crescent Street Waltham, Massachusetts 02154		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 7600-06-03
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (LWG) Hanscom AFB, Mass. 01731 Contract Monitor, T. Wirtanen		12. REPORT DATE (11) Jan 1977
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 29p. (16) 7600 (17) 06		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release, Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Azimuth Monitoring, Earth Crust Rotation and Translation Measurement, Laser Beam Position Reference, Electro-Optical Position Measurement.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A novel optical experiment is underway at the Air Force Geophysics Laboratories to measure rotation and translation of the earth's crust. The purpose of the experiment is to improve azimuth monitoring. The primary reference is a laser beam. The beam is optically split and aimed at two optical reflectors mounted on a common base in the earth's crust and normal to the horizontal. The reflected beam from reflector, (over)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

392 059

a plane mirror, is a measure of vertical and horizontal rotation. The reflected beam from the second reflector, a corner cube, is a measure of vertical and horizontal translation. The Dual Electro-Optical Biaxial Sensor described in this report is designed to sense the movement of the laser beams and record the results on an Incremental Magnetic Recorder. The specification to measure position of each of the two reflected beams over a dynamic range of 12 millimeters with a resolution of 0.01mm even with a large incident spot size, 20mm, is met by employing a large biaxial Schottky barrier photodiode. The excellent repeatability of this electro-optical position detector permits calibration of non-linearity with post experiment computation to reduce error in measurement to 0.01mm.

CONTENTS

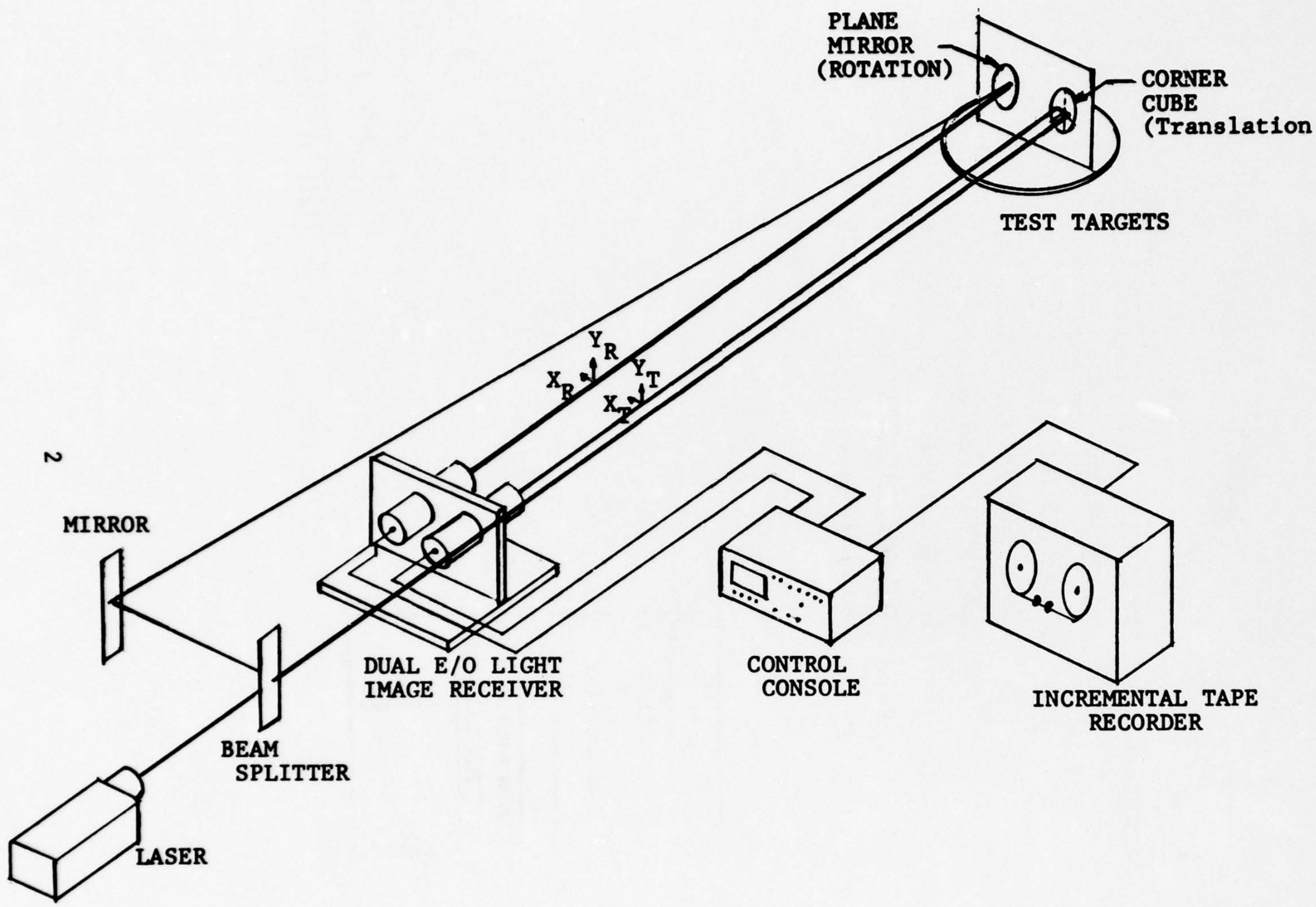

FIGURE 1 - AZIMUTH MONITORING EXPERIMENT

A DUAL ELECTRO-OPTICAL LIGHT IMAGE RECEIVER AND RECORDER

1. INTRODUCTION

The objective of this contract is the design, fabrication, test, and delivery of a prototype of a Dual Electro-Optical Light Image Receiver and Recorder which will be incorporated into an optical experiment underway at the Air Force Geophysics Laboratory (LWG). The optical experiment is a novel scheme to measure rotation and translation of the earth's crust. Ultimately this will lead to improved azimuth monitoring.

The optical experiment, Figure 1, will employ two reflective targets normal to the horizontal on a rigid platform in the earth's crust. A laser light source beam is split and the two resulting beams are each aimed at the center of one of the reflective targets. The optical arrangement is such that the resulting two reflected beams return to separate but closely spaced beam position sensors. One of the reflective targets is a plane mirror, therefore displacement of its reflected beam is a measure of rotation. The second reflective target is a corner cube and displacement of its reflected beam is a measure of translation. The design of the two beam spot position sensors and the recording of the position data on a specified Incremental Magnetic Tape Recorder, Kennedy Model 1600, is the subject of this report.

2. REQUIREMENTS

The Dual Electro-Optical Light Image Receiver is required to measure the movement of each of the two separate laser light beams. The desired measurements are horizontal and vertical displacement of the beam spot image centroids in a plane normal to the incident light beam. In order to facilitate the passage of the split laser beam, Figure 1, and remain in a position to receive the reflected return beams, the center to center spacing of the two beam position sensors is specified as at least 100 millimeters. The laser beams will travel a long distance to the targets, 100 meters, and return to the sensors. The beam dimensions will have increased from a small size to 20 millimeters. The incident spot on each sensor will have a 1 milliwatt intensity with a circular shape and Gaussian distribution. The total dynamic range of either light beam spot motion is specified as 12 millimeters ($\pm$ 6mm). Therefore, each sensor is required to have at least 20 + 12 or 32 millimeter usable aperture. The specification did not rule out the use of image forming optics in front of each sensor but did indicate that such optics were not desired. The beam spot position resolution is specified as 0.01 millimeters over the dynamic range. The possibility of sensor nonlinearity is recognized but the accuracy of 0.01 millimeter over the dynamic range is to be retained either by active compensation of nonlinearity or by sensor calibration and post experiment data processing correction.

The experiment will ultimately be conducted outside, therefore, operation in full daylight or at night is required. It was agreed at the initial, post award, technical meeting that it was in the best interest of the Air Force that the laser beam be modulated at 400Hz to reduce the cost of eliminating the effects of background light on the sensor position measurement. The Air Force will provide the modulated laser light source with a wavelength of 6328 angstroms. With this approach an inexpensive laser line optical filter may be used in conjunction with electronic blocking of D.C. signals from background light.

The motion to be measured as a result of earth crust disturbances will be very slow. It is specified that the beam position motion needs to be recorded at no faster than 1/minute and that the sensor signals be suitably converted to be recorded on a specified, Kennedy Model 1600, Incremental Digital Magnetic Tape Recorder. The format of the recorded data must be acceptable for processing by a CDC 6600 Digital Computer with a minimum additional new programming.

The operation of the equipment with turbulent air path disturbances was discussed at the initial meeting. It was agreed that the proposed fixed electronic filtering which was intended to minimize the effect of turbulence would be changed to a "variable" selector for differing time constants but that the sampling rate must be faster than the longest duration time constant. Including this feature permits employing short time constants for system alignment as well as the opportunity to experiment with alternate measurement integration time.

The equipment is to operate in an outdoors environment with data recording periods of ½ hour during non-inclement weather. Standby periods of from 7 to 14 days are anticipated, therefore, the equipment must be suitably housed to protect it from inclement weather, dust, insects, etc. The temperature will range from -10 to +35 degrees centigrade.

The sensor assembly must readily mount on a concrete pillar and weigh less than 50 pounds. Any interconnecting cabling must be flexible to minimize torque on the measurement station. Controls for operating the system and interfacing the sensors with the tape recorder are required.

3. SELECTION OF A LIGHT IMAGE POSITION SENSOR

The motion to be measured, rotation and translation of the earth's crust, is expected to be a very slowly varying parameter. This property is important when considering the planned optical experiment. The laser light beams will traverse distances of the order of 100 meters. The beam dimensions will expand to a diameter of 20 millimeters and the shape as well as the centroid of the beam energy will be affected by air path turbulence. This "shimmer" is a relatively high frequency when compared with the earth's crust motion. Time averaging of the centroid of the beam spot energy distribution will significantly reduce the effect of air path turbulence. The key to employing this technique is to select a beam spot position sensor which is responsive to the centroid of the light distribution falling on its light sensitive surface.

There are two basic approaches to the measurement of an extended light spot centroid position. The closed loop measurement where the sensor is electro-mechaniclaly repositioned to null, and pick offs on the drive system provide a measure of displacement. The second approach is the open loop measurement where a sensor is selected which is capable of measuring the total dynamic range of the problem without repositioning. The disadvantage of closed loop approach is primarily cost. The closed loop scheme will always have a finite deadspace which determines the ultimate position resolution. As one imposes smaller and smaller values of resolution on the closed loop system, its complexity, size and cost increase. The major disadvantage of the open loop sensor is that most, if not all, exhibit a degree of nonlinearity. A second consideration is whether the sensor is fabricated on a continuous light sensing surface or comprised of a number of discreet elements in a quadrant or matrix array. This latter form suffers from nonuniformity of response versus light spot position as well as nonlinearity. There are spot position detectors which offer a continuous sensitive surface. The biaxial Schottky barrier photodiode is an example.

The specification places great emphasis on the sensor's capability to resolve small motion with the provision that any nonlinearity is correctable. Experience with the biaxial Schottky barrier photodiode in a more severe requirement led to a high degree of confidence that it has more than the required position resolution and although it is nonlinear at extreme spot displacement, it is highly repeatable. This latter characteristic lends itself to active correction of nonlinearity or post experiment computer processing correction based on precise calibration of the nonlinearity.

The open loop beam spot position sensor approach utilizing a large biaxial Schottky barrier photodiode was selected as the lowest cost approach to achieving all of the technical objectives of the specification.

The biaxial photodiode is basically a device that generates an electronic current proportional to light intensity. It may be used in a photovoltaic mode or with a back bias in a photoconductive mode. A manufacturer, United Detector Technology, Inc., has devised a large square continuous device 35 x 35 millimeters, Model SC-50, shown pictorially in Figure 2.

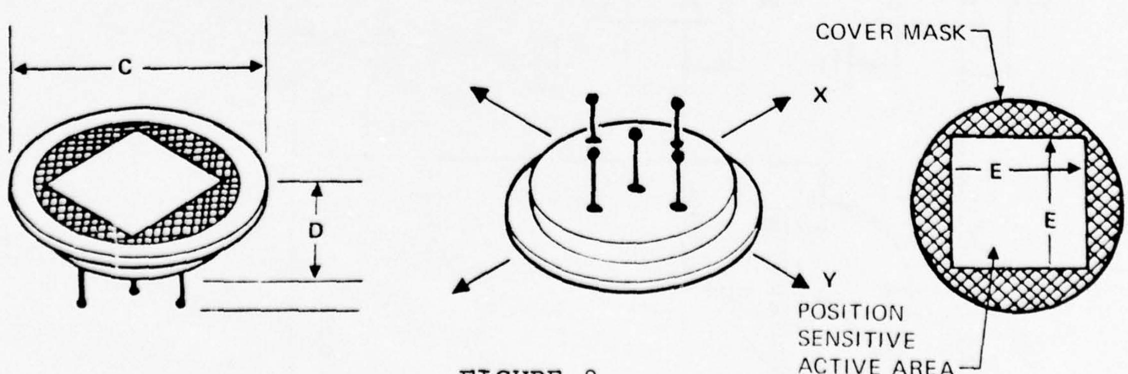

FIGURE 2

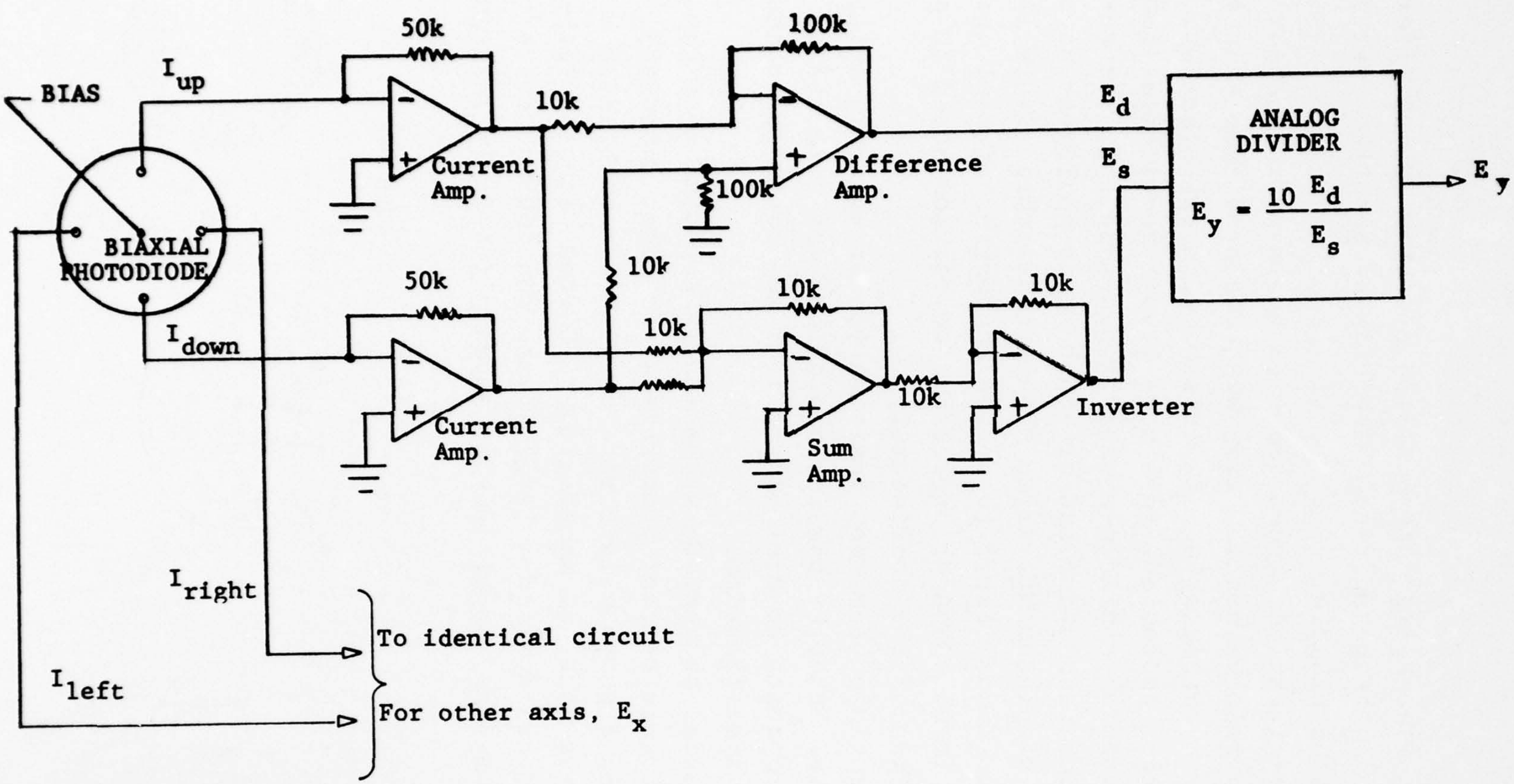

FIGURE 3 - DUAL AXIS PHOTODIODE POSITION SENSOR

This device with four connections; one on each side, has the effect that equal current flows out each terminal when the light spot is centered, and as the light spot moves toward one terminal and away from its opposite terminal, a current unbalance occurs. This difference in current is proportional to the displacement of the light spot centroid from center position. Employing contact pairs one can then sense light spot position change in two directions. A common contact is provided to bias the cell. Figure 3 is a schematic of the basic circuit for one axis for this sensor and can be used to describe the basic functioning of the device. Since the photodiode is a current source, the preamplifier is a current to voltage operational amplifier where the output voltage is $E_o = IR_f$. The next stage is a difference amplifier which subtracts up from down or left from right voltage signals. The result is a voltage proportional to light spot displacement from center. This difference voltage, E_d, is also proportional to the light intensity so that if no corrective action were taken the gradient of the position measurement would vary with intensity, I. Fortunately the sum of the two currents is also proportional to intensity but not to light spot position changes. One straight forward solution then is to divide the difference by the sum to arrive at a signal proportional to position but not intensity.

$$K_3 E_{y,x} = \frac{K_1 E_d \cdot I}{K_2 E_s \cdot I}$$

This is shown in Figure 3 where an analog divider is employed. An alternative is to use the sum signal to control the intensity of the light source; i.e. automatic gain control. This approach has merit since it closes the loop and maintains a constant operating point. We do not have control of the amplitude of the light source, hence the divider approach will be used. Either compensation method also corrects for gradient changes in the photodiode caused by temperature. The simple form electronics shown in Figure 3 is all that is required for a single channel light spot position sensor.

It was agreed that the Air Force would provide a 400Hz modulation for the light source to allow A.C. signal amplification. In conjunction with a laser optical filter for each sensor A.C. amplification will reduce the D.C. light background to a negligible effect on performance. A.C. amplification also minimizes D.C. drift in the initial amplifiers and reduces 1/f noise. The specified laser spot intensity at 6328A° is 1 milliwatt. The efficiency in the optical filter, 100A°BW, is 0.8 and the response of the photodiode at 6328A° is 0.8, resulting in a net loss of 0.64. The response to motion of the selected UDT sensor, SC-50, is 0.2μa for 0.01mm change. The noise terms to be considered are from, (Let Δf = 1Hz)

1) Dark current, $I_d = 1 \times 10^{-6}$ amps

$$I_s^2 = 2\, q\, I_d\, \Delta f, \qquad q = 1.6 \times 10^{-19} \text{ coul.}$$

$$= 2 \times 1.6 \times 10^{-19} \times 10^{-6}$$

$$= 3.2 \times 10^{-25} \text{ amp}^2/\text{Hz}$$

2) Resistor noise, R_f = 60,000

$$I_r^2 = 4\, KT\, \Delta f/R_f, \qquad 4\, Kt = 1.6 \times 10^{-20} \text{ joules}$$

$$= 1.6 \times 10^{-20}/5 \quad 10^4$$

$$= 3 \times 10^{-25} \text{amp}^2/\text{Hz}$$

3) Preamp current noise at 400Hz

For 1448 op amp. 2×10^{-25} amp^2/Hz

The rms noise input at one preamplifier is

$$I_n = \left[(I_s^2 + I_R^2 + I_a^2)\right]^{\frac{1}{2}}$$

$$= \left[(3.2 + 3 + 2) \times 10^{-25}\right]^{\frac{1}{2}}$$

$$= 1 \times 10^{-12} \text{ amps}$$

There are two channels involved in taking the difference. Therefore,

$$I_n = (2)^{\frac{1}{2}} \; (1 \times 10^{-12})$$

$$= 1.4 \times 10^{-12}$$

The position signal current for 0.01mm to difference noise current is

$$SNR = \frac{0.128 \times 10^{-6}}{1.4 \times 10^{-12}}$$

$$SNR = 3.4 \times 10^{4}$$

In essence, electronic noise from the sensor or preamplifier is not a significant factor in determining resolution. This was noted in the breadboard where no electronic shot noise was observed. The limiting factor is more likely the dynamic range; that is, a comfortable signal for 0.01mm is 10 millivolts which in turn results in $\pm$ 6 volts for $\pm$ 6 millimeters. This is about the maximum linear value of typical operational dividers. The divider selected has an inherent noise of less than 1 millivolt so resolutions of 0.001mm are feasible. An analog to digital conversion of 4½ BCD digits will be used so that resolution of 0.001 will be recorded.

4. ELECTRONIC DESIGN

The electronic design of the Dual Electro-Optical Light Image Receiver and Recorder has taken advantage of the require-

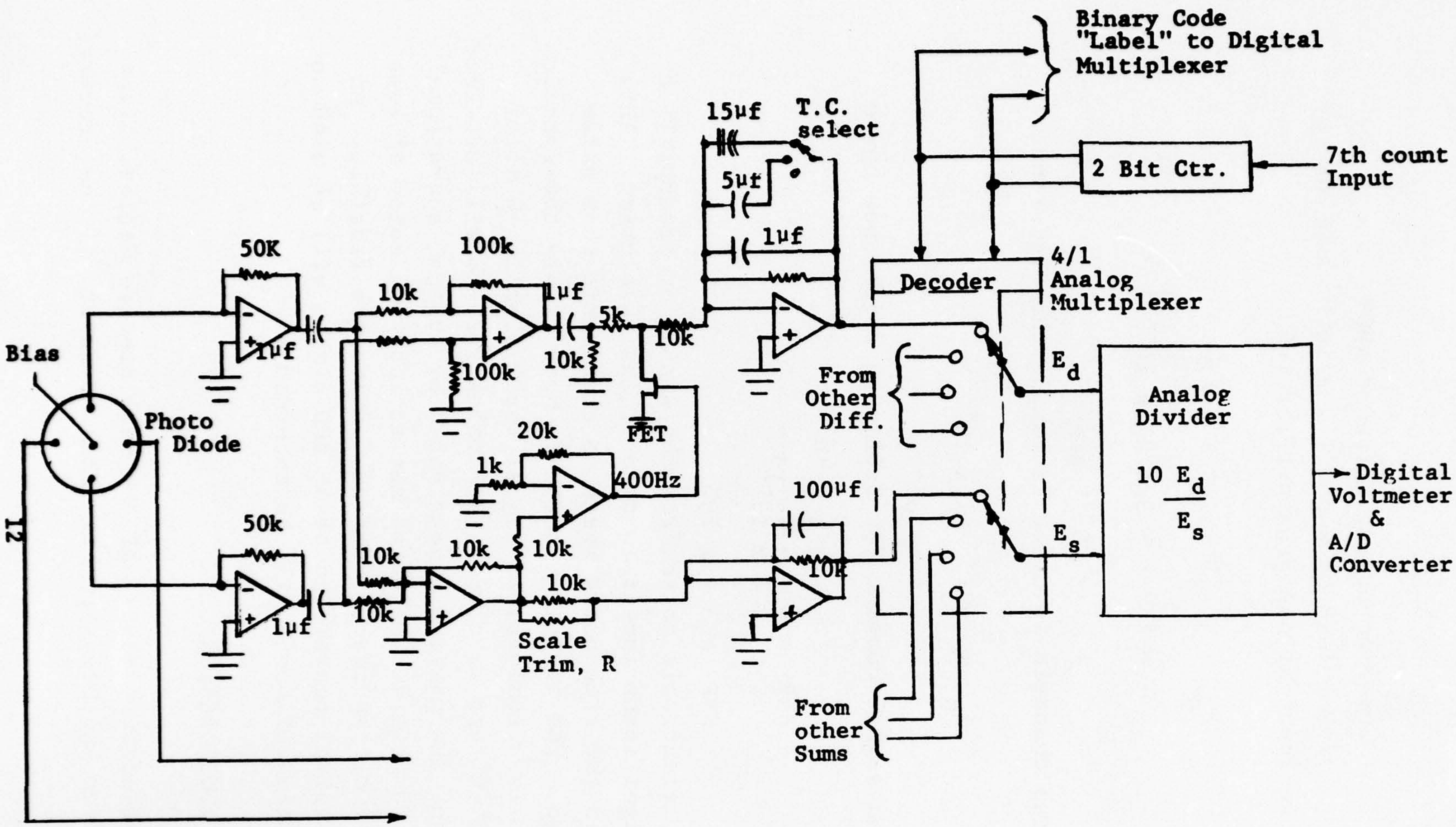

FIGURE 4 - ANALOG 400Hz SENSOR SIGNAL PROCESSING
WITH SEQUENTIALLY MULTIPLEXED DIVISION

ment to sense and incrementally record slowly varying phenomenon. The significant aspect of this design approach is that time is available to multiplex a single analog divider and sequentially process each of sum and difference signal from the four position signal amplifiers. This saves cost and space. Secondly, a single off the shelf digital panel voltmeter can be used for a dual purpose. The model selected, a Fairchild Model 5400, has an internal bipolar analog signal to binary coded decimal (BCD) converter. This A/D converter provides parallel BCD that can be triggered from an external pulse source after which the BCD data is held at data output connections until a new trigger pulse is received. Time is available between sensor data sampling to then stepwise multiplex the parallel BCD and write it incrementally on the tape recorder. A bonus is derived by using a digital panel meter. It is also a display for observing the measurement data values and for system setup and alignment.

Figure 4 is a schematic of the final electronic design of the analog sensing and signal processing for one of the four beam spot position signals. The form and operation is described previously in Figure 3. A.C. coupling of the amplifiers is added and a 400Hz bipolar detector follows the difference amplifier. This bipolar phase detector is a field effect transistor (FET) driven by a 400Hz amplifier. The drive amplifier derives this 400Hz reference from the sum signal amplifier. The FET switch opens and closes in synchronomism with the signal. When the signal is in phase the output is a linear positive D.C. voltage proportional to amplitude. Conversely, when the signal is out of phase the output is a linear negative voltage proportional to amplitude; i.e., a bipolar signal. This signal is applied to an integrator with a selectable time constant. A switch on the control subsystem front panel selects the desired time constant.

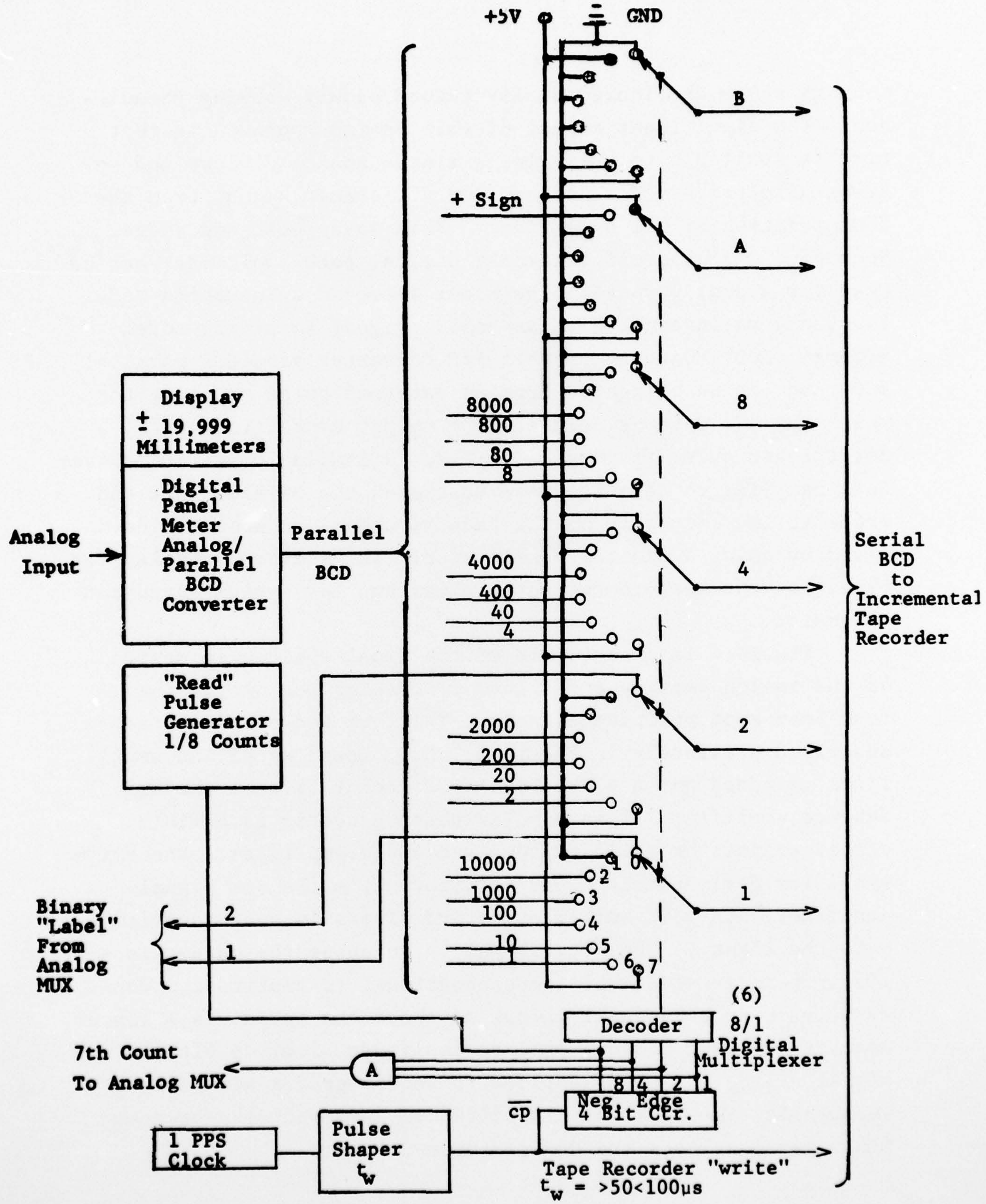

FIGURE 5 - ANALOG TO BCD FORMAT CIRCUIT

The scale of the measurement is adjusted by trimming the value of the sum signal amplifier. The scale is set at the factory for 1 volt/millimeter.

An Analog Devices Inc. Model 7501 Dual 4/1 Analog Multiplexer (MUX) sequentially connects a single Analog Devices Inc. Model 436B Analog Divider to each pair of sum and difference signals. The analog MUX has an internal binary count decoder which is connected to a 2 bit binary counter. A pulse for every 7 counts of the system clock (1 PPS) is applied to this counter such that the MUX is advanced every 7th count of the system clock resulting in a new value of signal voltage from the next channel appearing at the output of the analog divider. The binary count, 0, 1, 2, 3 has been used to label which channel, translation or rotation, $Y_R = 0$, $X_R = 1$, $Y_T = 2$, $X_T = 3$ is applied to the divider. This binary count drives a decimal display on the front panel of the control subassembly and is passed on to the tape recorder via the digital MUX in order to "label" the channel being recorded.

The components critical to maintaining a stable gain value have been carefully selected. All resistors are temperature stable metal film. The D.C. integrators, analog MUX and divider are enclosed in a thermally controlled box which maintains the temperature within $\pm 5^{\circ}C$.

The schematic, Figure 5, is the electronic design employed to interface the multiplexed analog signals with the incremental magnetic tape recorder. The requirement is that any format selected be compatible with a CDC 6600 Computer. The specified Kennedy Model 1600, Incremental Tape Recorder is a standard 7 track recorder. An IBM BCD standard format has been selected. In this format the first of the 7 tracks (C) is a true level for BCD parity and is internally generated by the recorder. The remaining 6 tracks, B, A, 8, 4, 2, 1 are used to sequentially compose a word of 8 character length. Each word is comprised of first, a code character for "label".

The makeup of this character is arbitrary. A hard wired true level for track "A" plus the binary code from the analog MUX on track "2" and "1" automatically writes $Y_R(0) = \&$, $X_R(1) = /$, $Y_T(2) = S$, $X_T(3) = T$. The second character of a word is the $\pm$ sign, comprised of a hard wired true level on "B" and an automatic true or zero on "A" generated by the digital voltmeter. The word characters three through seven are the decimal value of the measurement with the most significant digit character three and LSB character seven. The eighth and last character of the word is hard wired to record the ASCII symbol for "word separator".

This format is generated by six digital MUXES as shown in Figure 5, SN74151. A system clock, a 555 timer, provides a continuous pulse stream at 1 pulse per second. This pulse is shaped by a one shot, 9602, to form a pulse of at least 50 but less than 100 microseconds duration. This pulse is the primary "write" command for the tape recorder. The specification for the recorder is that the write command be no longer than 100 microseconds and that the input data be valid for at least 50 microseconds. This same pulse is applied to a 4 bit counter, SN7493, which counts on the negative edge. The counts 1, 2, 4, are applied to the binary decoder of six digital MUXES. As a result a "write" - MUX step; "write"-MUX step; sequence occurs where the digital MUXES will not step until the "write" duration is complete. Therefore, the data for each "write" interval is always valid as required.

The digit panel voltmeter is a slope-integrating analog to BCD converter. It requires 900 milliseconds for it to reach 0.01% of its final value. The data being recorded on the 8th step (position 7) of the digital MUXES is hard wired and not connected to the Digit Panel Meter (DPM). Therefore, any transient invalid data from the DPM is not seen by the recorder. We use this interval to advance the analog MUX and allow the DPM to settle by stepping on the 7th count by AND gating count 1, 2, and 4. The 8 count from the 4 bit counter is applied to "8th" count pulse generator, 9602, and issues a short, 1 millisecond "read" pulse for the DPM Analog Digital Converter. The converter reads the settled voltage and produces a sign value, most significant bit and 4 decimal digits which are then in "hold" until the next read pulse. All of the A/D conversion is accomplished in 50 milliseconds. This allows more than adequate time, 950 milliseconds, before the "write" command is given for writing digital MUX position "0". This cycle repeats; writing a word, advancing the analog MUX, reading the voltmeter, writing a new word as long as desired.The digital MUX count "0" through "7" is also displayed. A switch on the front panel of the control subassembly will interrupt the automatic cycle and permit manual writing of BCD data. Six toggle switches are employed to connect "true" or "zero" to the recorder six data lines. Any given data code representing annotation of the tape for ancillary experimental data, date, time, etc. can be entered by pushing a "manual" push button.

Another switch on the front panel may be toggled to "align". This also inhibits the "write" command and switches the "read" input to an auxiliary timer, a 555, which issues a pulse four times/second for using the DPM to align the system. Another push button switch permits manually advancing the analog multiplexer from one position to the next where it stays when in this "align" mode. One can determine which of the Y_T, X_T, Y_R, X_R, positions are being measured by observing the analog MUX decimal display.

The four analog signals from the integrators, prior to division, are brought out to test points on the front panel. The scale factor is not the same as after division but may be used for zeroing the system. A sum signal from each sensor is also brought to a test point and these can be used to determine the approximate laser intensity. The scale is 1 volt/milliwatt.

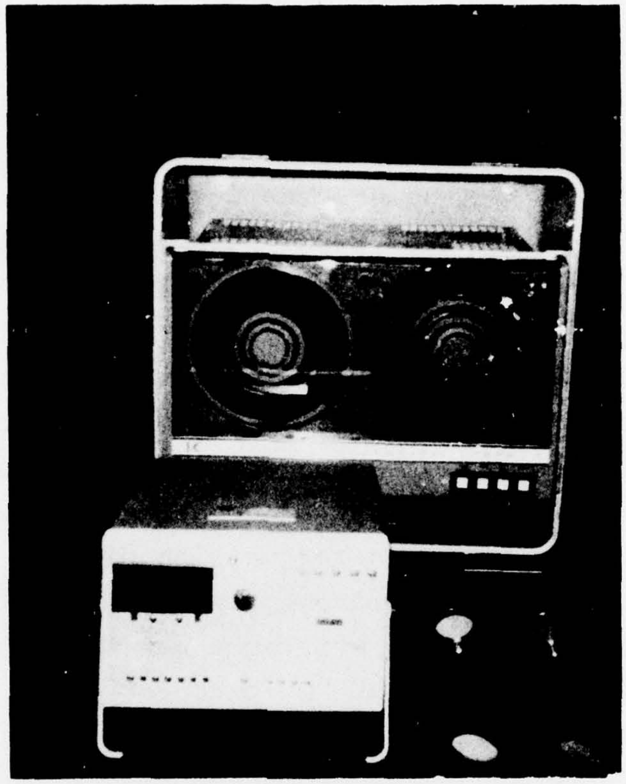

FIGURE 6

DUAL ELECTRO-OPTICAL LIGHT IMAGE RECEIVER AND RECORDER SYSTEM

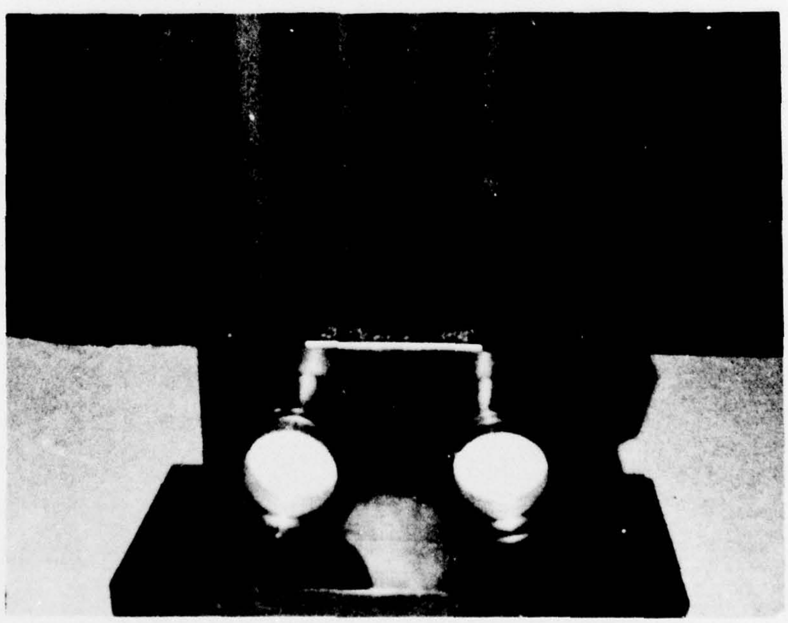

FIGURE 7

DUAL ELECTRO-OPTICAL RECEIVER ASSEMBLY

5. PHYSICAL DESIGN

The Dual Electro-Optical Light Image Receiver System is comprised of three subassemblies as shown in Figure 6; there is the Dual Electro-Optical Receiver assembly, the Control System assembly, and the Incremental Tape Recorder assembly.

The Dual Electro-Optical Receiver assembly, Figure 7, is made up of a base plate of flat aluminum, 11 x 16 x ½ inches, with 4 large mounting holes. The mounting holes are on centers suitable for mounting on prefabricated optical tables with holes on 2 inch centers or on a concrete pillar. A vertical mounting plate 1½ inch thick is used to mount the two laser beam spot position sensors. Sensor mounting is accomplished by providing two slightly oversized holes each with a "c" clamp slot and clamping screw. The two holes are 100mm on centers. A precise zero index is machined on the face of the vertical mounting plate over the top center of the sensor holes. A large, 1 inch hole, and 1 inch diameter semicircular cutout have been cut from the mounting plate to allow passage of the laser beams. Each sensor is identical. An aluminum tube of 3 inch diameter with threaded front end and a rear end cap held by screws is used. The biaxial photodiode is mounted in an insulating ring and inserted into the tube against an internal wall from the front. The 2 inch diameter laser line optical filter is inserted next and then a gasket. The protective window is inserted next, followed by a rubber sealing gasket. A large threaded ring is used to hold this assembly of components in the tube. A standard military circular receptacle is on the back cover plate. On the inside of this plate is a set of standoffs on to which a circuit board is mounted containing preamplifying electronic components. Sufficient wire length is used so that the preamp circuit board may be operated outside the tube while connected to the photodiode rear pin connections. After testing, this rear assembly is inserted into the rear of the tube and held with screws. The zero position, $Y_T = 0$, $Y_R = 0$ of the photodiode is set approximately by noting the rear pin alignment. During test and calibration each of the two sensor tubes are rotated until there is no cross coupling of Y and X signal output. A line is inscribed on the outside of each tube indicating "zero" which is then set to match the zero index on the mounting plate. Since the overall, sensor to analog divider, scale factor may be different each tube receptacle has an identifying nameplate, J_1 for translation, Y_T and X_T, and J_2 for rotation, Y_R and X_R. This marking notation is carried throughout the remainder of the control system and displays by proper wiring interconnection. The weight of the complete Dual Receiver Assembly is 25 pounds.

The Control System is enclosed in a standard instrument case, BUD TR6102, which is 7 x 11 x 13 inches. This case is basically a rigid rectangular integral horizontal center and vertical front frame. Two aluminum removable main covers, top and bottom are supplied as is an aluminum front panel. A separate matching flat plate aluminum chassis was procured. The flat chassis slides into groves in the horizontal frame and the front panel attaches both to the chassis and front vertical frame by screws. In this way the panel and chassis are held in the basic frame work. The top cover is directly removable for access to internal circuit boards on the top of the chassis. The bottom cover is used for system interconnection. Four military circular receptacles are on the rear vertical wall of this cover. Internal wiring length is sufficient to loosen this bottom cover and fold it back for access to circuit boards on the bottom of the flat plate chassis. The four receptacles have been mounted on the cover wall from the inside. Therefore it is possible to unfasten these four receptacles and unscrew the front panel from the vertical frame and slide the assembly of front panel and chassis completely out of the framework. The system control may now be operated with complete access to all internal components.

A number of wire wrapped circuit boards and system power supplies are mounted to the top and bottom of the chassis. Each board is individually removable. A thermally controlled enclosure is also mounted on one of the boards and contains the temperature sensitive components, analog integrators, analog multiplexer, and analog divider. An adjustable thermostat ($\pm$ 1°C) is affixed to the enclosure cover and is set for 30°C. Wire-wound resistive heaters are attached to the wall of the enclosure.

The Digital Voltmeter is a self-contained unit mounted on the front panel. The unit has two printed circuit connectors on the rear for interconnecting to the control system wiring. The meter is a Model 5400 Fairchild 4½ Digit Type which has been modified, as specified by the manufacturer, to permit operation by an external trigger. The meter display decimal point was selected so that the display readout is $\pm$ 19.999 volts full scale. The analog scale for each sensor parameter Y_T, X_T, Y_R, X_R is 1 volt/millimeter, therefore, the meter reads directly in millimeters to 0.001mm. The light emitting diode,(L.E.D.), decimal display is 0.5 inch character height.

The front panel also has additional displays; a 0.5 inch decimal L.E.D. display for indicating the position of the analog multiplex (0 to 3) and one for indicating the position of the digital multiplexers (0 to 7). A three-unit 0.5 inch L.E.D. decimal display indicates the number of "words" written on the tape recorder and this display will freeze in the event the tape recorder issues a signal that a writing error has been detected. The system continues in a normal mode to record but the data is suspect for words beyond the indicated count. An auxilliary L.E.D. is used to indicate the presence of a write error signal.

Six 3 position toggle switches are on the front panel to allow entry of binary coded data (BCD) manually on the magnetic tape. Six individual L.E.D.'s show the state of the BCD data in manual or during normal operation. A push button on the front panel is used to manually enter BCD incrementally. A toggle switch places the control system in either manual or automatic recording mode.

A toggle switch permits transferring the control system functioning from automatic recording to "align". This stops the automatic stepping of the multiplexers and increases the voltmeter read rate to 4/second. Pushing a pushbutton switch advances the analog multiplexer to any desired parameter, $Y_R(0)$, $X_R(1)$, $Y_T(2)$, $X_T(3)$ for individual measurement. Another pushbutton may be pushed, "Reset", which clears all counters to zero when alignment is complete. The toggle switch is now returned to down position for automatic recording.

A three position wafer switch is on the front panel to provide the capability to simultaneously change all four sensor channel integration times.

The tape recorder functions; loads, end of file, end of record, and rewind, may be operated from pushbuttons on the front panel.

There are seven test points on the front panel, Y_T, X_T, Y_R, X_R, Sum_T, Sum_R, and Ground.

The four connectors on the bottom cover rear wall have identifying nameplates; J_3(Connect to Sensor J_2), J_4 (Connect to Sensor J_1), J_5(Connect to Recorder), and J_6(Connect to 115 volts 60Hz). A 60Hz line fuse is mounted on the bottom side of the chassis.

The specified Kennedy Model 1600 Incremental Tape Recorder is installed in a fiberglass carrying case. The instrument is normally operated in a laboratory or controlled environment. Care should be taken in handling the instrument and space in the case has been provided for installing desiccant if condensation on the tape is a problem.

6. TEST AND CALIBRATION

The contract requirement is to design, fabricate, assemble, and test the Dual Electro-Optical Light Image Receiver and Recorder. It was agreed that the approach proposed to employ an open loop laser beam position sensor and calibrate its nonlinearity would be used.

An optical bench with an available ½ milliwatt laser with wavelength 6823A^{o} was assembled. Two precision micrometer driven stages were mounted on the bench such that a sensor can be mounted normal to the laser beam and positioned in X and Y. Two millimeter dial gages were installed to measure the X and Y position over a range of greater than $\pm$ 6 millimeters. The dial gage graduations were 0.01 millimeter and visual interpolation to better than 0.005 is possible. The laser beam was expanded to 20 millimeters and a spatial filter used to establish a Gaussian distribution.

Employing this precision positioning arrangement, each sensor was tested with all of the deliverable supporting equipment. The prior breadboard tests had determined very closely the gain setting resistor values. It was decided to use fixed resistor trimming rather than variable potentiometers since the possibility of someone inadvertently changing a setting is always present. It would be difficult to restore the correct calibration without a precision optical bench as described above. Should recalibration be required it is important to note that

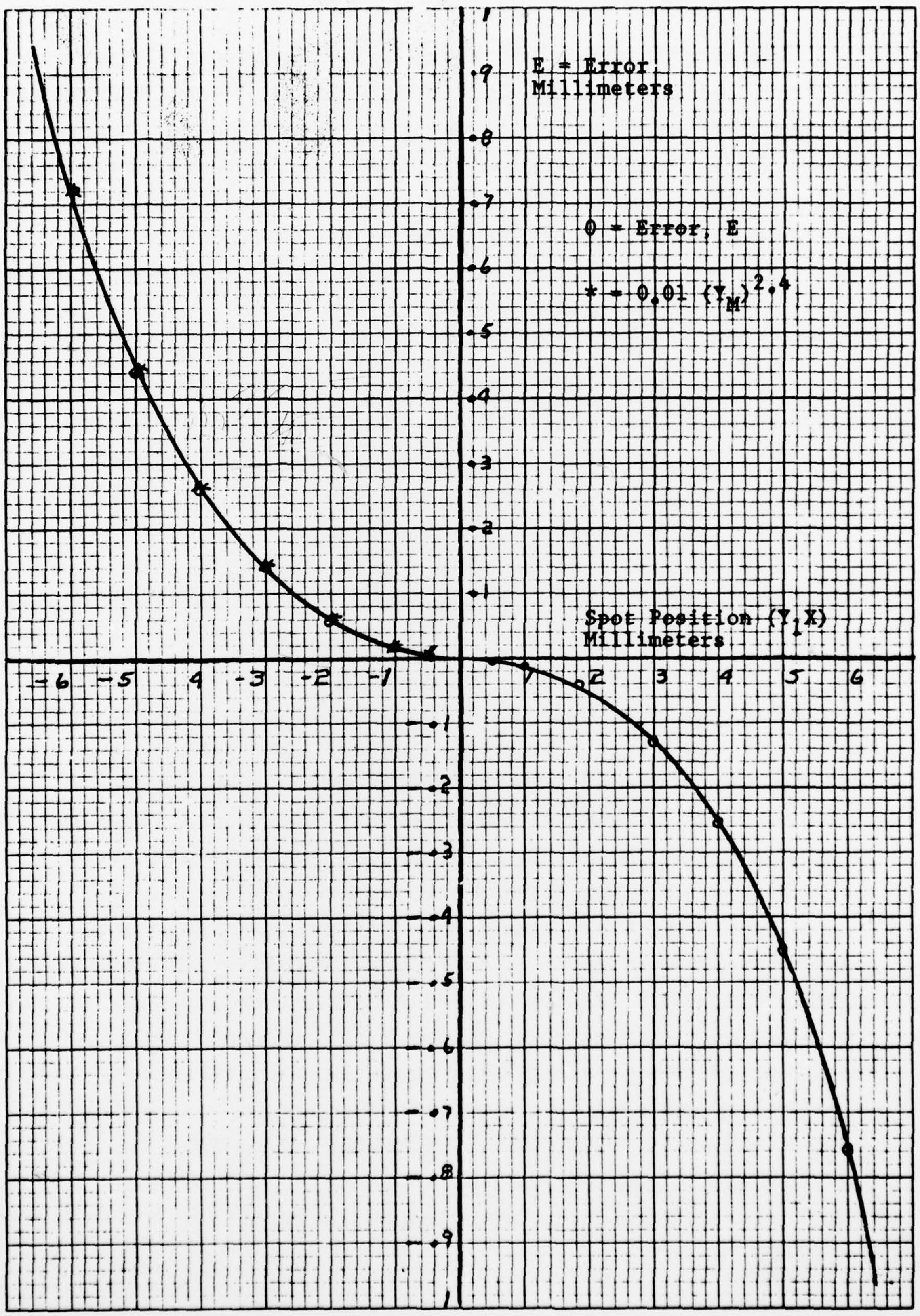

FIGURE 8 - NONLINEAR CHARACTERISTIC CURVE

the sensor X and Y zero index must be in a proper position. No cross coupling should be evident when the laser spot is moved in one axis direction to $\pm$ 6mm.

After proper alignment, two trim steps were taken. With the output of the sensor (400Hz) at zero, a D.C. voltage is introduced into the integrator to reduce any residual operational amplifier offset to zero. The second trim is to adjust the value of the sum voltage into the analog divider such that at mechanical displacement of $\pm$ 1 millimeter results in 1 volt on the Digital Panel Meter.

Having trimmed each of the scale of the four sensor outputs, Y_T, X_T, Y_R, and X_R, the next step is calibration. Several calibration runs of $\pm$ 7mm were done with the breadboard and also with the final equipment. There was no evidence of hysteresis and repeatability was within 0.01mm. There was evidence that hand pressure on the micrometer stages resulted in noticeable change. Prior to final calibration the system was allowed to warm up for 10 minutes.

The raw calibration data has been provided to the technical monitor. The nonlinearity was as expected from data supplied by the photodiode manufacturer. The error from true value is plotted in Figure 8. Here we see a characteristic curve approaching a square law. The error, E, can be almost perfectly predicted by formulation of

$$E = 0.01\ (Y \text{ or } X)^{2.4}$$

as shown by the overlayed values indicated on the plot of Fig.8. Therefore, programming the computer

$$\pm Y_T = Y_M \pm 0.01\ (Y_M)^{2.4}$$

Where Y_M = measured value and errors of 0.01 or less will be maintained beyond $\pm$ 6mm.

Long term stability was checked but required a long warmup time for the ½ milliwatt laboratory laser which was not designed for ultimate beam position stability. It was shown that over the specified one half hour recording period the zero position, or a given value position, did not drift greater than 0.01mm.

7. CONCLUSIONS

A Dual Electro-Optical Light Image Receiver and Recorder has been designed, fabricated, tested, and delivered to the Air Force Geophysics Laboratory (LWG). The performance testing demonstrated a laser beam movement resolution of 0.01mm and a dynamic range of greater than 12mm when the dimension of the beam spot was 20mm and intensity less than 1 milliwatt. The large biaxial photodiode selected as the laser beam position sensor exhibited excellent repeatability of position measurement suitable for precise calibration of nonlinear response. Given this calibration it is feasible to compute the error caused by nonlinearity and correct the measurement to within the specified requirements.